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DEVELOPMENT TEST SUMMARY IN SUPPORT OF X-20 ELEVON STRUCTURAL TEST PROGRAM

JOHN C. GROGAN

TECHNICAL REPORT AFFDL-TR-65-191

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
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FOREWORD


This report was prepared by John C. Grogan of the Project Engineering Group, Structures Test Branch, Structures Division of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. It contains a general summary of significant results obtained during the development test program conducted in preparation for the X-20 Elevon Structural Test Program.

This report covers work conducted from January 1964 to July 1964.

The manuscript of this report was released by the author September 1965 for publication as an RTD Technical Report.

The research and development work upon which the report is based was accomplished under Task No. 136804, "Re-entry in Hyperthermic Structures," of Project No. 1368, "Structural Design Concepts."

This technical report has been reviewed and is approved.


FRED J. PECK, JR.
Chief, Structures Test Branch
Structures Division

ABSTRACT

The contents of this report are oriented exclusively toward test procedures, test hardware and test techniques involving advanced type structures. It contains a general

summary of significant results obtained during the development test program conducted in preparation for the X-20 Elevon Structural Test Program.

CONTENTS

SECTION		PAGE
I	Introduction	1
II	Discussion	2
III	Summary and Conclusions	8

ILLUSTRATIONS

FIGURE		PAGE
1	Specimen and Lamp Arrangement for Power Requirements Tests	9
2	Power Required (KW/ft^2) v.s. Distance from Lamps to Specimen . . .	10
3	Power Increase (% from 2 inch Reference) v.s. Distance from Lamps to Specimen	10
4	Temperature Lag Under LT-1200 Lamp Holders v.s. Temperature Level	11
5	X-20 Elevon Time-Temperature Program	12
6	Temperature Distributions on Corrugated René 41 Panel	13
7	Temperature Distributions on Slotted Research, Inc. Water Cooled Reflector	14
8	X-20 Elevon Slotted Water Cooled Reflector	15
9	Temperature Distribution on Rod in Close Proximity to Heat Lamps . .	16
10	Test Set-Up for Load Rod Temperature Tests	17
11	Temperature Distribution on Thin René 41 Load Strap in Close Proximity to Heat Lamps	18
12	Load Strap and Heater Arrangement on X-20 Elevon	19
13	Time Temperature Program for Heater Evaluation	20
14	Thermocouple Switching System Used for the X-20 Elevon Test Program	21
15	Comparison of Actual Load and Programmed Load from Edison Load System	22

SECTION I

INTRODUCTION

1. This report is a summary of significant results obtained during the development test program conducted in preparation for the X-20 Elevon Structural Test Program. The areas that will be covered are those that are considered to have general application to forthcoming structural test programs. A brief outline of the topics to be covered are presented below:

a. Power requirements for lamp to specimen distances of 2, 3, 4 and 5 inches (see Paragraph 1, Section II).

b. Temperature gradients on the specimen in the shaded areas of the Lux-Therm (LT 1200) ceramic double lamp holders for lamp to specimen distances of 2, 3, 4 and 5 inches (see Paragraph 2, Section II).

c. Temperature gradients on corrugated panels (that is, temperature differences between peaks and valleys of the corrugations). (See Paragraph 3, Section II).

d. The temperature distribution on Research, Inc. water cooled reflectors when some water channels are eliminated from the reflector. (On the X-20 elevon set-up, slots had to be cut in the reflectors to permit passage of load straps). (See Paragraphs 4 and 5, Section II).

e. Data-Trak programmer modifications which permitted controlled temperature decay rates in the event of an emergency abort situation (see Paragraph 10, Section II).

f. Method to establish proportional band settings to permit good temperature control (see Paragraph 12, Section II).

g. Back-up system to permit control of one zone with a thermocouple (t/c) from an adjacent zone in the event of a control t/c malfunction (see Paragraph 11, Section II).

h. Thirty-four channel load system checkout using the Data-Trak as the program generator (see Paragraph 13, Section II).

i. Modifications to a fatigue Edison unit for time dependent load spikes (see Paragraph 13, Section II).

j. Temperature distributions on load straps and rods that come in close proximity to heater lamps (see Paragraph 6, Section II).

k. Temperature limits of stainless steel lamp holders (see Paragraph 7, Section II).

l. Optimum point where cooling is required for ceramic lamp holders and lamp quartz envelope (see Paragraph 8, Section II).

m. Lamp orientation with reference to R.I. reflector water channels (that is, lamps parallel with water channels v.s. lamps perpendicular to water channels). (See Paragraph 4, Section II).

n. Pyro-Metric Model 602 heater evaluation (see Paragraph 9, Section II).

SECTION II

DISCUSSION

1. Power requirements as a function of lamp to specimen distance were determined by oven tests. The test set-up and other pertinent information are presented below:

a. The oven used for these series of tests was made from 3000°F fire brick and had inside dimensions of 31 inches x 31 inches x 12 inches deep. The oven sides were lined with 3 layers of 1/8 inch thick "Fibrefrax" insulation. Two windows (9" x 2-1/2" Vycor) were provided for visual inspection.

b. The specimen consisted of a .010 inch René 41 corrugated panel removed from the Boeing Hot Structures Model. It had a trapezoidal shape 22 inches long with end dimensions of 12-1/2 and 17-1/2 inches respectively. Thirty-seven chromel-alumel (24-28 gage) thermocouples were welded to the specimen in selected locations to provide data for the tests mentioned in Section I (see Figure 1). The panel specimen was supported by angle sections to minimize warpage and to provide a 3-inch clearance between the bottom of the oven and the specimen. The emissivity of the specimen was approximately 0.80.

c. Test temperatures were applied by heaters consisting of Research, Inc. water cooled reflectors, Lux-Therm (LT-1200) ceramic double lamp holders (with no cooling air), and Westinghouse 1500, T-3, CL/HT quartz infrared heat lamps. The lamps were oriented parallel to the reflector water channels which were perpendicular to the corrugations of the specimen. The double lamp holders were located in the center between water channels on 1-5/8 inch centers giving an equivalent lamp spacing of 0.812 inches. Each row of lamps was staggered to minimize specimen temperature gradients (See Figure 1 for heater dimensions and layout).

d. Figure 2 is a plot of power required (KW/ft^2 reflector) v.s. lamp to specimen distance for the test configuration described

above. These power data were obtained with a recording wattmeter at a constant specimen temperature of 1770°F.

e. Figure 3 is a plot of lamp to specimen distance v.s. additional power required (in percent) from power required at lamp to specimen distance of 2 inches. These percentage values were taken from the data presented in Figure 2.

2. Figure 4 is a plot of specimen temperature at the control thermocouple locations v.s. temperature lag under the shaded area of the Lux-Therm (LT-1200) double lamp holders for lamp to specimen distances of 2, 3, 4 and 5 inches. The temperature lag under the lamp holders was obtained by taking the difference between thermocouple 19 and the average of thermocouples 12, 17, 33, and 36 (Reference Figure 1). These data were obtained using the heater arrangement, specimen and oven configuration described in Paragraphs 1a, 1b and 1c of Section II. It is noted that two data points are plotted at the 1770°F temperature level. The larger values were recorded 5 seconds after reaching the 1770°F plateau while the lower values were recorded after 10 minutes on the plateau. Specimen temperature was applied by following the programmed time-temperature curve presented in Figure 5. All data of Figure 4 (with the exception of the plateau point at 1770°F) were recorded during transient conditions. If plateaus were established at each temperature level the gradients under the lamp holders would be considerably less. From this data, the optimum lamp to specimen distance was selected at 4 inches. This was the setting used for the X-20 elevon program with good results.

3. Figure 6 is a sketch showing temperature gradients along the corrugations of the René panel described in Paragraph 1b, Section II. All data plotted was obtained during the 1770°F temperature plateau of Figure 5 at a lamp to specimen distance of 4 inches.

4. Orienting the lamps parallel to the water channels offers two significant advantages (See Figure 7). These are:

a. Any necessary modifications to the basic reflector "off the shelf" sizes (14-1/2" x 12" or 14-1/2" x 24") can be accomplished with less manhour expenditure.

b. This arrangement lends itself to reflector slotting (for passage of load straps, deflection devices, etc.) more readily. Test data has shown that under the same set of conditions (that is, same water flow rates, reflector size, power levels, etc.) the two arrangements (lamps perpendicular v.s. lamps parallel to the water channels) will produce the same reflector temperature.

5. Because of the load fitting arrangement on the elevon, four 8-inch long slots had to be cut in the reflectors to accommodate the load straps. To accomplish this, four water channels had to be eliminated from the reflectors. Figure 7 and 8 show a typical reflector with slots and the corresponding test temperatures in various locations for both the upper and lower surface reflectors. Since the temperatures are not excessively high in the region of the slots, it appears that sufficient reflector cooling could be accomplished with fewer water channels. This would reduce the reflector cost considerably and also make the reflector more adaptable for slotting, size modification, and so forth. Further test work in this area is being considered. Pertinent notes associated with Figure 7 are as follows:

a. The heaters shown in Figure 7 were located close to the geometric center of the elevon. Hence, boundary effects are not a consideration.

b. The reflector temperature data shown were maximum values recorded during the time-temperature excursion of Figure 5.

c. The maximum upper surface temperature was 1600°F.

d. The maximum lower surface temperature was 1770°F.

e. Lamp to specimen distance was 4 inches.

f. Water flow rates were 4.3 gallons per minute through a reflector area of 4.5 square feet. The water inlet pressure was 80 psig and the outlet pressure was 50 psig.

g. The change in reflector water temperature (that is, water out - water in) was about 20°F.

6. Several tests were conducted to determine temperature distributions on load straps and rods that are located in close proximity to the lamps. Figure 9 is a plot of rod temperature distribution as a function of rod length for a given specimen temperature (see Figure 10 for details of test set-up). Figure 11 is a plot of X-20 elevon load strap temperature distribution for both upper and lower surfaces as a function of specimen temperatures. Data for strap temperatures were obtained from thermocouples located just adjacent to the lamps and 18 inches above the specimen surface (See Figure 12). No insulation or forced cooling was used on the load straps.

7. Stainless steel lamp holders, without cooling, should not be used to produce sustained specimen temperatures (60 minutes or longer) of 2000°F with power levels around 16 KW per square foot. This is based on test runs conducted with the following parameters:

a. Specimen - Three square feet of built-up panels consisting of .015 inch thick Di-Sil coated molybdenum heat shields (emissivity .80) one inch thick Q-felt insulation blanket backed up by a René 41 corrugated panel. All tests were conducted with the specimen mounted in an insulated oven made from fire brick.

b. Heater - Research, Inc. water cooled reflectors (9 units, each 4 by 12 inches) with a water flow rate of 6 GPM. Each reflector unit contained four 1500 T3/HT General Electric lamps (36 lamps total) mounted in R.I. Model 8352-2 stainless steel double lamp holders. The lamps were oriented parallel to the reflector water channels. No cooling was used for either the lamps or holders. Lamp to specimen distance was 2 inches.

c. Test Results - Seven cycles of temperature application as per the time-temperature curve of Figure 13 were applied to the specimen without any lamp failures. Each cycle had a 2000°F temperature plateau of 17 minutes. During the eighth cycle several lamp holders failed completely due to oxidation of the stainless steel holder. Lamp extension leads were also severely oxidized to the point of failure. The total test time at 2000°F was 130 minutes. Lamp holder oxidation was evident during the third cycle.

8. From test data it was determined that lamp (quartz) envelope cooling is a requirement for sustained (90 minutes or longer) specimen temperatures of about 2200°F with power levels around 25 KW per square foot. This is based on a test conducted with the following parameters:

a. Specimen - Typical X-20 wing panel consisting of a Di-Sil coated molybdenum (.015 inches thick) heat shield (emissivity .80), one inch of insulation (Q-felt) backed up by a Rene' 41 corrugated panel. The specimen was 1 square foot in size and was mounted in an insulated oven made from fire brick.

b. Heater - Research, Inc. water cooled reflector (6 GPM water flow rate), Lux-Therm (LT-1200) double lamp holders, 1500 T3/HT General Electric lamps on 1/2 inch centers (24 lamps total) with no cooling air for either the lamps or holders. The lamp to specimen distance was 2 inches.

c. Test Results - Twenty-five kilowatts were applied to the lamps (193 volts and 130 amps) for two hours producing a specimen temperature of 2200°F. There were no distinct lamp failures for this time period, however, after 90 minutes of run time the lamps began to sag in the center. At the conclusion of the test (two hours of run time) this sag was measured at 3/8 inch. Moderate to severe lamp bulging was also evident.

9. Evaluation tests were conducted on two Pyrometric Model 602 heaters. These heaters consisted of an all ceramic reflector cast from a refractory oxide with the support fittings made from stainless steel. The lamps are supported by special ceramic holders

with the lamp end seals and lead wires imbedded in the ceramic holders. This heater is unique in that it requires no cooling whatsoever for specimen temperatures up to 2000°F. All tests were conducted in an insulated oven. The specimen was a typical X-20 wing panel as described in Paragraph II-8a. Each unit measured 6 by 12 inches and contained 6 lamps on 1 inch centers. One unit was tested with six GE 1500 T3/HT lamps while the second unit was tested with six GE 2000 T3/HT lamps. Tests on each unit were conducted separately. No lamp failures or lamp replacements were made for each test sequence. The lamps appeared to be in excellent condition at the termination of the evaluation tests. Test data are tabulated in Tables I and II.

10. The desired time-temperature profiles for the X-20 Elevon Test Program were generated on two Research, Inc. Model FGE 5110 Data-Trak programmers. These units were modified for controlled cooling (5°F per second) in the event of an emergency abort situation. This modification consisted of installing a clock motor in the unit which drove the program signal down scale at a constant rate when the abort switch was energized. Tests on the modified units produced average decay rates of 4.5°F per second. Requirements for decay rates other than 5°F per second could be satisfied by merely changing the gear ratios in the clock motor assembly.

11. The largest control zone size employed for the X-20 Elevon Test Program was one square foot using one thermocouple per zone for control. Control thermocouple reliability was obtained by employing a manually operated switching system that permitted control of one zone with a thermocouple from an adjacent zone in the event of a control thermocouple malfunction. The control zone areas were small enough to permit good control in this manner. Figure 14 illustrates the thermocouple switching system used for the elevon tests. For normal operation with all thermocouples functioning properly the double pole double throw switch is in Position BA. In the event of a thermocouple malfunction, the switch pertaining to the trouble zone is placed in Position BC. Control is then restored by the thermocouple signal

TABLE I
DATA FROM EVALUATION TESTS OF PYRO-METRIC MODEL 602 HEATERS

Test No.	Lamp Size (All GE)	Specimen Temp (°F)	Lamp to Specimen Distance	Power Level KW/Ft ⁻²	Support Frame Temp °F (Max)	Reflector Temp °F (Max)	Test Time @2000°F Hours	Remarks
1	1500T3	2000	2"	13.94	872	942	9.45	Lamps new at start of test
2	1500T3	2000	3"	18.98	986	982	4.53	No lamp or reflector failures
3	1500T3	2000	3 1/2"	21.60	1050	1023	4.50	No lamp or reflector failures
4	1500T3	2000	4"	23.82	1103	1155	3.71	No lamp or reflector failures
TOTAL							22.19	Lamps in excellent condition. Slight cracks in ceramic reflectors but not serious. Minimum of oxidation on stainless steel support frame. No lamp replacements or failures for tests 1 thru 4. Original lamps and heater used for all tests.

TABLE II
DATA FROM EVALUATION TESTS OF PYRO-METRIC MODEL 602 HEATERS

Test No.	Lamp Size (All GE)	Specimen Temp (°F)	Lamp to Specimen Distance	Power Level KW/Ft ⁻²	Support Frame Temp °F (Max)	Reflector Temp °F (Max)	Test Time @2000°F Hours	Remarks
1	2000T3	2000	2"	13.84	920	870	11.47	Lamps new at start of test
2	2000T3	2000	3"	20.88	1025	910	4.50	No lamp or reflector failures
3	2000T3	2000	3 1/2"	26.22	1080	915	4.58	No lamp or reflector failures
TOTAL							20.55	Lamps in excellent condition at conclusion of tests. Slight cracks in ceramic reflector but not serious. Support frame in good condition. No lamp replacements or failures for tests 1 thru 3. Original lamps and heater used for all tests.

from the adjacent zone. This system can only be used if the zone sizes are fairly small and the adjacent zones have the same power requirements.

12. Past test experience has led to an empirical method of establishing Proportional Band settings for the controller units (Research, Inc., General Electric and Westinghouse) to achieve good temperature control. The method discussed below will not always give the best Proportional Band settings for each and every test set-up but in general it provides a good reference starting point. Proportional Band setting K in $^{\circ}\text{F} = \frac{(10^{\circ}\text{F}) (KW/\text{lamp (max)})}{0.5 \text{ KW}}$. The

constants of 10°F and 0.5 KW were established empirically by past test experience. The term $KW/\text{lamp (max)}$ defines the maximum KW output for one single lamp based on the maximum power available to the particular temperature zone being considered. For example, determine the approximate Proportional Band setting for a temperature zone consisting of twelve 1500 T3 (GE) lamps wired in series parallel (that is, six sets of two lamps each). A 50 KW Research, Inc. Ignitron unit will be used for power distribution and assume a transmission loss of 10 volts or 590 volts available at the heaters. From the lamp charts it is found that each series parallel lamp set will produce 4.034 KW or 2.017 KW per lamp. Thus, the Proportional Band setting for this will be: $K = \frac{(10^{\circ}\text{F}) (2.017 \text{ KW})}{0.5 \text{ KW}} = 40.34^{\circ}\text{F}$.

13. The 34-channel load system was originally planned to be used for the X-20 Elevon test program. A dummy jig was erected as a checkout test bed for the system. A load reacting beam was designed to produce equivalent predicted elevon deflections. The maximum expected deflection for the X-20 elevon at the point of load application was only about 1 inch. Many checkout runs were conducted on the dummy test rig and all proved unsatisfactory. Gain settings required to produce correct loading produced severe load cylinder strut oscillations. Based on these results the 34-channel system was dropped in favor of a modified fatigue Edison unit (Model 6SC). The modification consisted of mounting a constant speed motor to a gear box which produced the desired loading rates of two and three minutes (three minutes from zero to maximum load for the up load conditions and two minutes for the down load conditions). The exact hydraulic ram pressure and load rate was determined for each condition in a special jig isolated from the specimen. This system was linear through the entire load spike and proved very satisfactory. See Figure 15 for a plot of actual load v.s. programmed load. The loading rates for this program were quite small, higher rates could produce some nonlinearities.

14. Further checkout work with the 34-channel system led to a stable system by applying pressure to only the tension side of the strut and eliminating the compression side. This is noteworthy and would have application for test programs involving relatively stiff structure.

SECTION III

SUMMARY AND CONCLUSIONS

General conclusions are presented below. These findings are based on the results of tests using the specimen and heater configurations defined in the Discussion Section of this report. Other heaters and specimen combinations will produce somewhat different results but it is felt that this information will be useful for preliminary planning and a guide to establish some general ground rules for elevated temperature testing.

1. The power required for specimen equilibrium temperatures in the 1800°F range varies almost linearly with lamp to specimen distance (from 2 inches to 5 inches). The recorded power levels to maintain an equilibrium specimen temperature of 1800°F, for the test set-up discussed in Paragraph II-1, were 8.1, 10.4, 11.9 and 13.2 kilowatts per square foot for lamp to specimen distances of 2, 3, 4 and 5 inches respectively.
2. To minimize temperature gradients on the specimen due to lamp holders, gaps between heaters, lamp spacing, and so forth, lamp to specimen distances should never be less than 3 inches. The optimum distance was found to be 4 inches.
3. Orienting the lamps parallel rather than perpendicular to the water channels of Research, Inc. Model No. WC-14 water cooled reflectors offers two significant advantages. These are: (1) modifications to the basic "off the shelf" sizes can be accomplished easier and cheaper and (2) the parallel arrangement lends itself to reflector slotting (for passage of load straps, deflection devices, etc.) more readily. Tests have shown that the cooling effectiveness of the reflector is the same for either the parallel or perpendicular arrangement.
4. Temperatures on thin (0.022 in.) Rene' 41 load straps (not thermally protected) located in close proximity (within 0.125 to 0.25 inches) of the infrared heating lamps will experience temperatures of about 20 to 30 percent higher than the specimen temperature during transient heating rates of 4°F per second. During steady state equilibrium conditions load temperatures just adjacent to the lamps will lead specimen temperatures by about 4 to 5 percent. See Paragraph II-b for details of the load strap and heater configuration (as well as the temperature ranges) used to obtain these data.
5. Stainless steel lamp holders, without cooling, should not be used on heater assemblies designed to produce sustained (60 minutes or longer) specimen temperatures of 2000°F with power levels around 16 kilowatts per square foot.
6. Infrared lamp (quartz) envelope cooling is a requirement for sustained (90 minutes or longer) specimen temperatures of about 2200°F, or higher, with power levels near or above 25 kilowatts per square foot.
7. Pyrometric Model 602 heaters are good for producing specimen temperatures of 2000°F with power levels up to 22 kilowatts per square foot for sustained periods of time (in excess of 20 hours).
8. Model FGE 5110 Data-Trak programmers can be easily modified to permit controlled cooling necessitated by an emergency abort situation.
9. Model 6SC Fatigue Edison hydraulic load controllers produce a linear load output for loading rates up to 0.8 percent of total load per second.

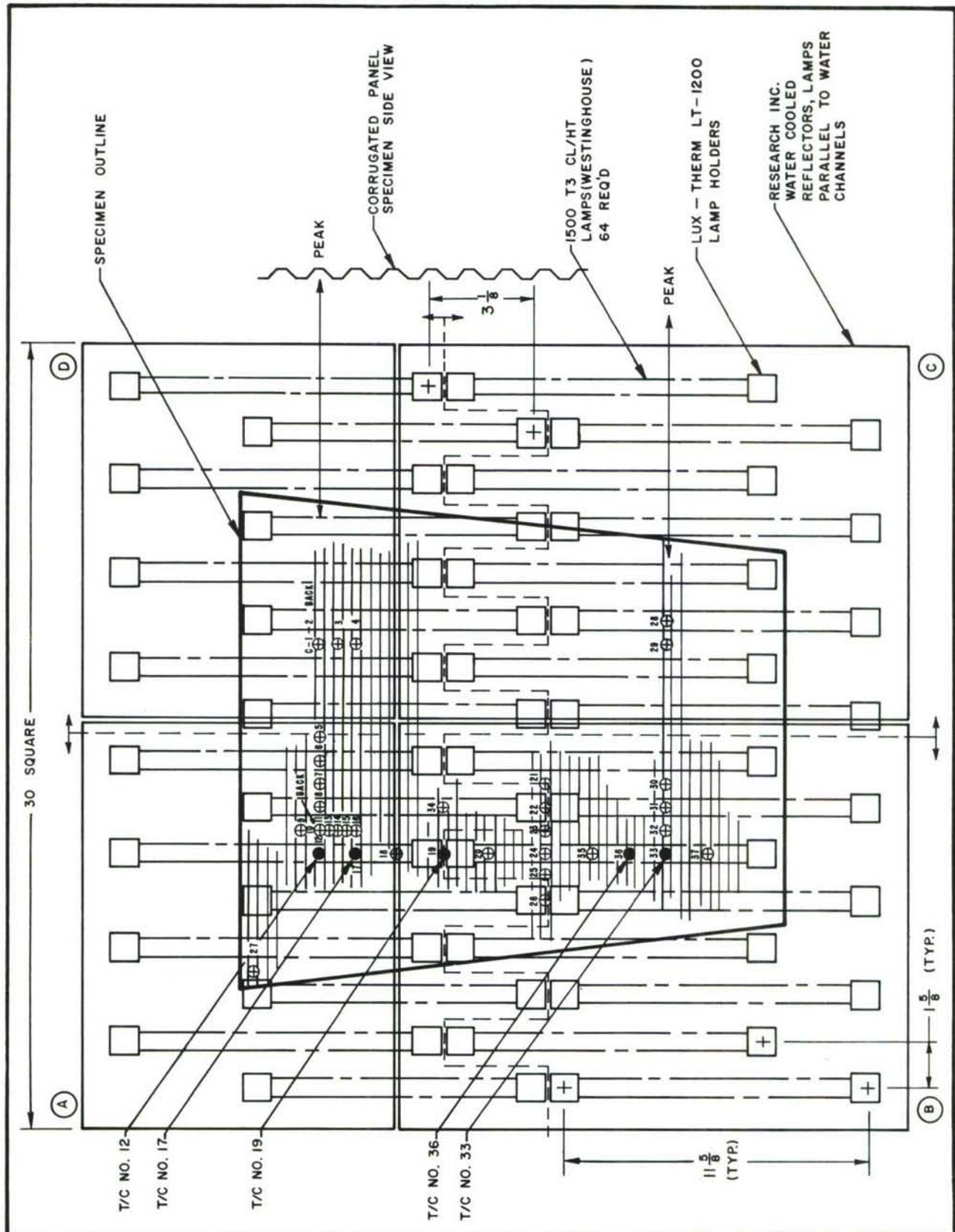


Figure 1. Specimen and Lamp Arrangement for Power Requirements Tests

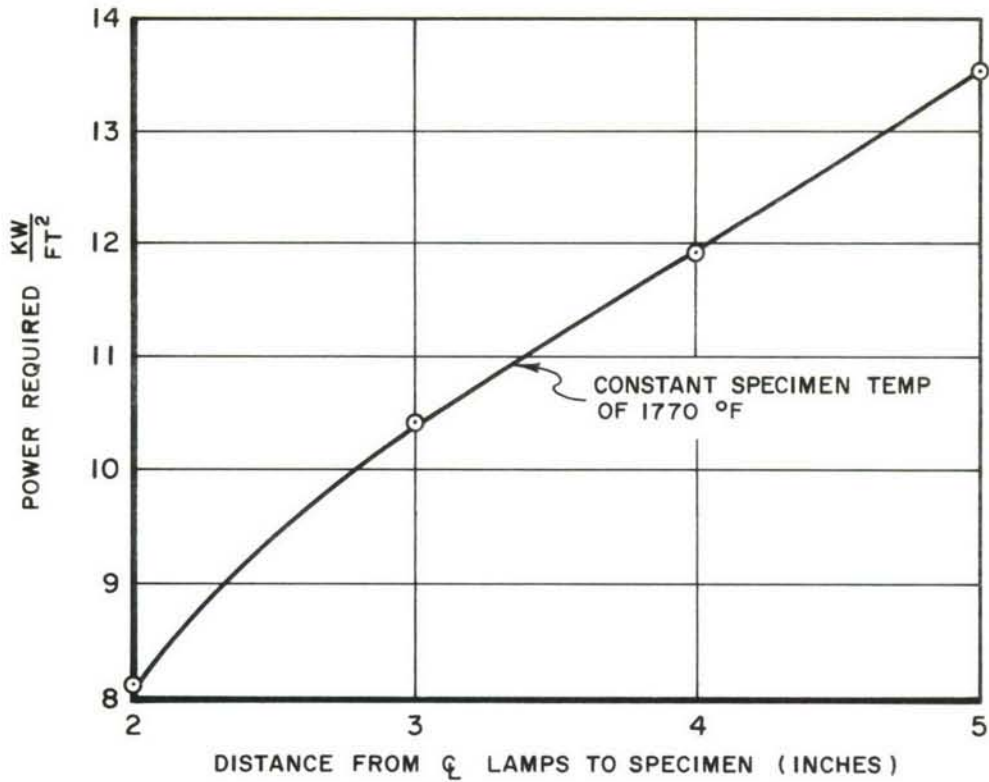


Figure 2. Power Required (KW/ft²) v.s. Distance from Lamps to Specimen

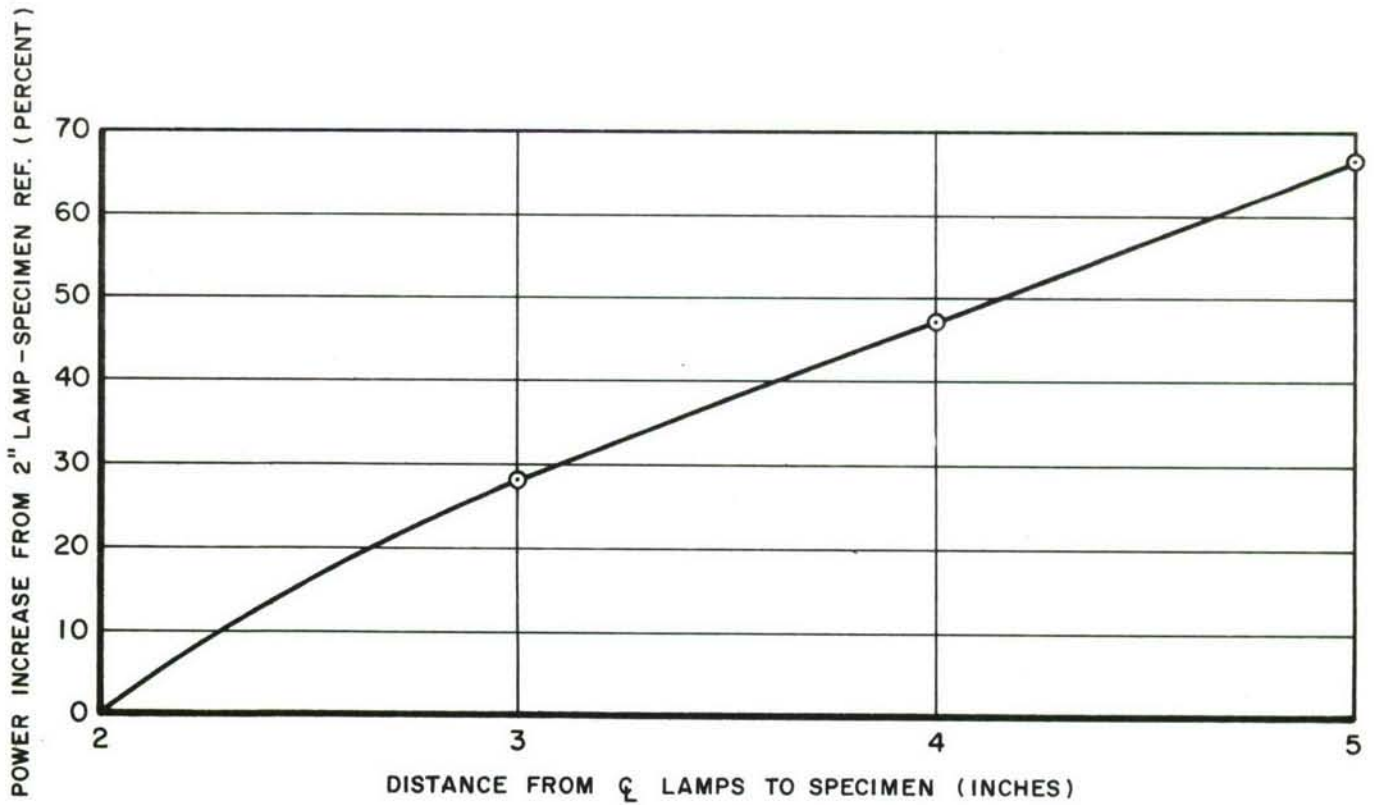


Figure 3. Power Increase (% from 2 inch Reference) v.s. Distance from Lamps to Specimen

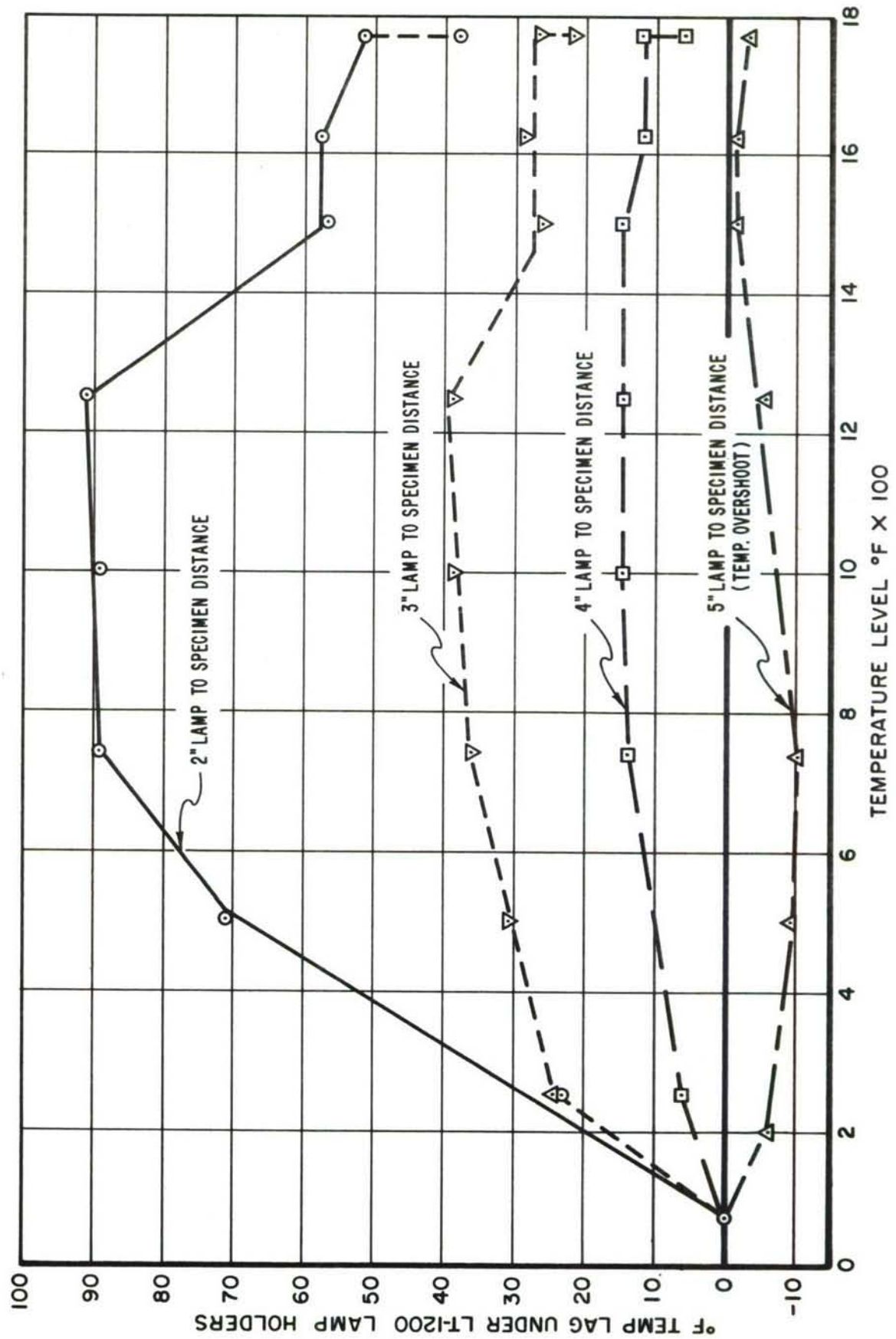


Figure 4. Temperature Lag Under LT-1200 Lamp Holders v.s. Temperature Level

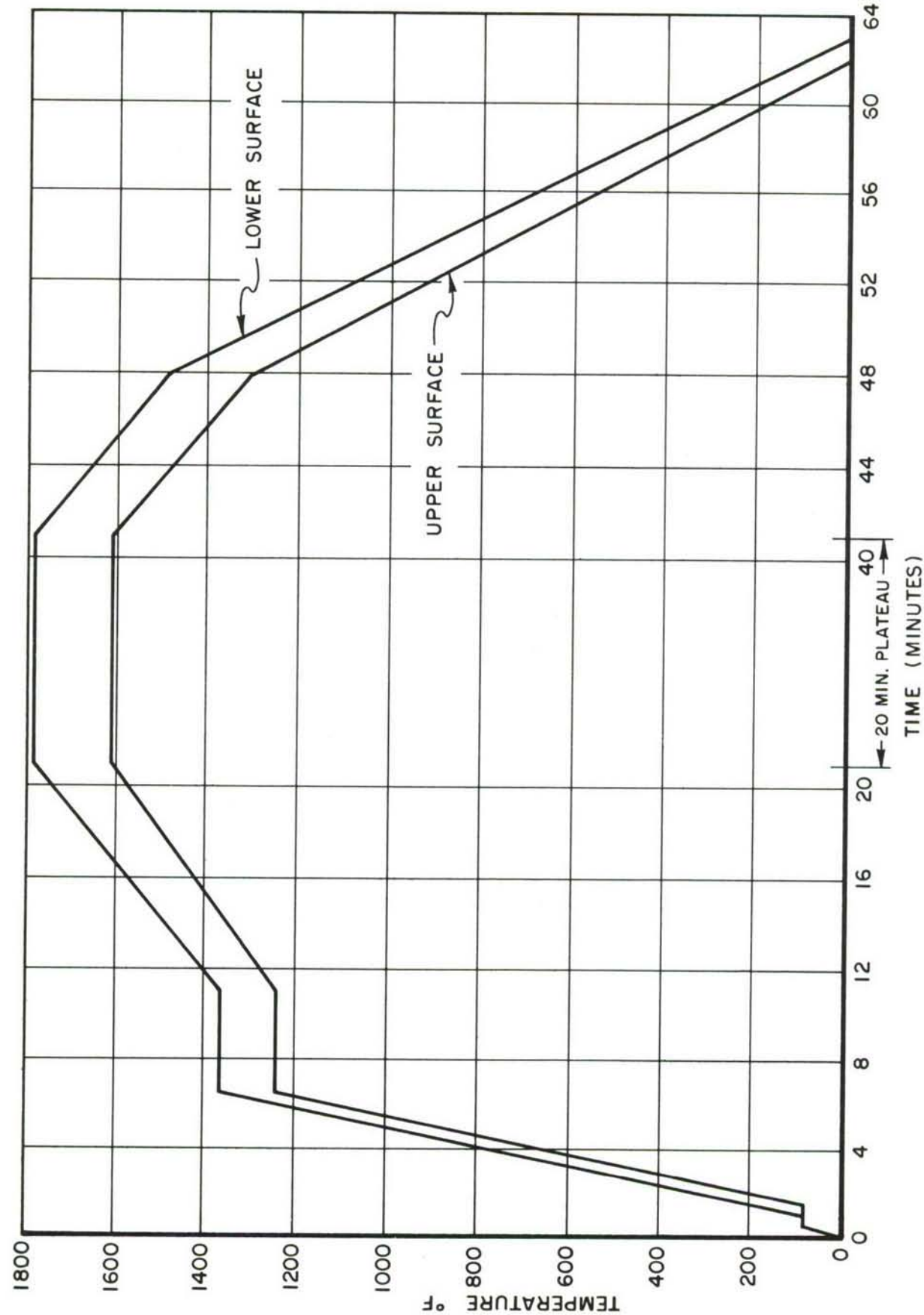


Figure 5. X-20 Elevon Time-Temperature Program

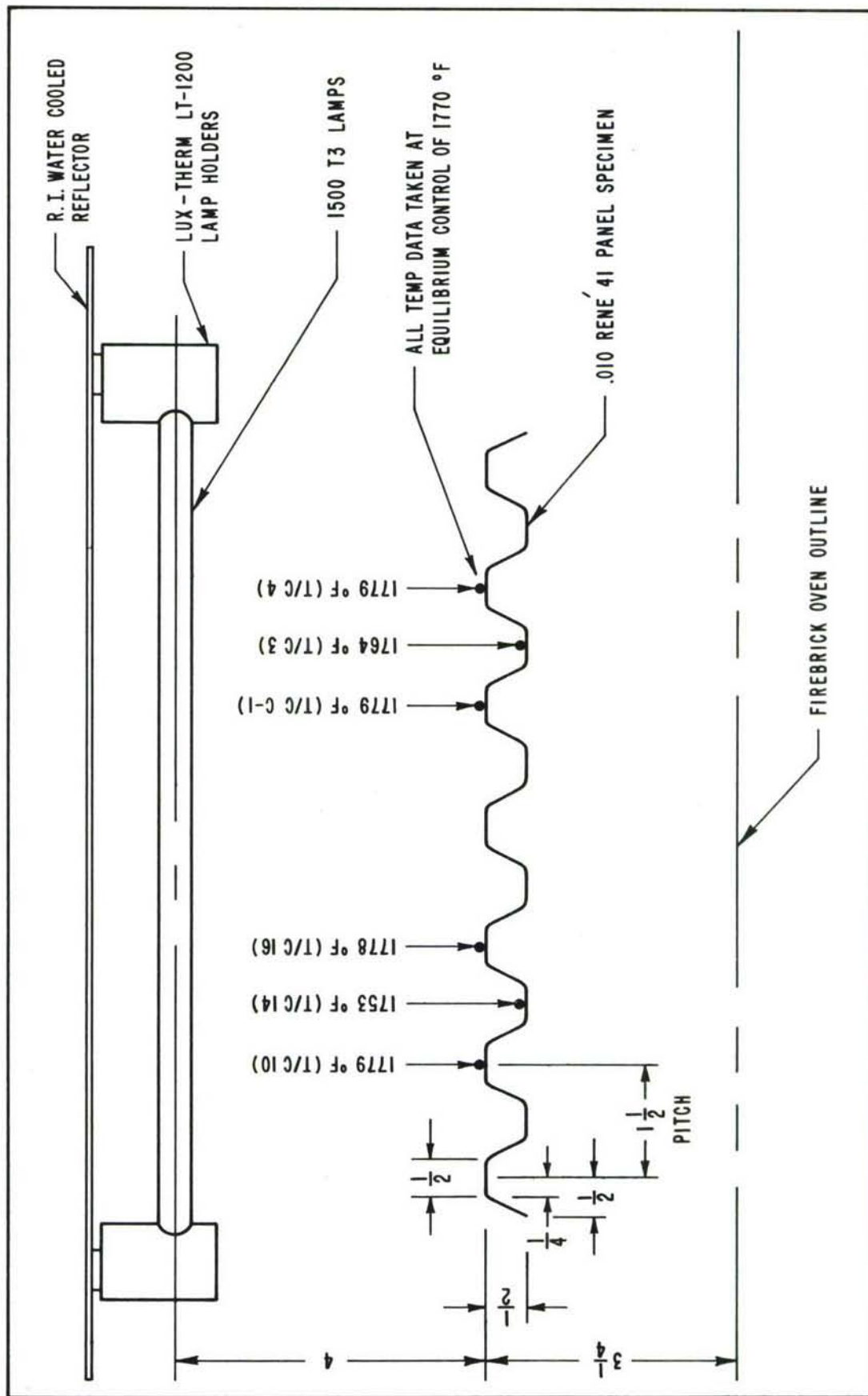


Figure 6. Temperature Distributions on Corrugated René 41 Panel

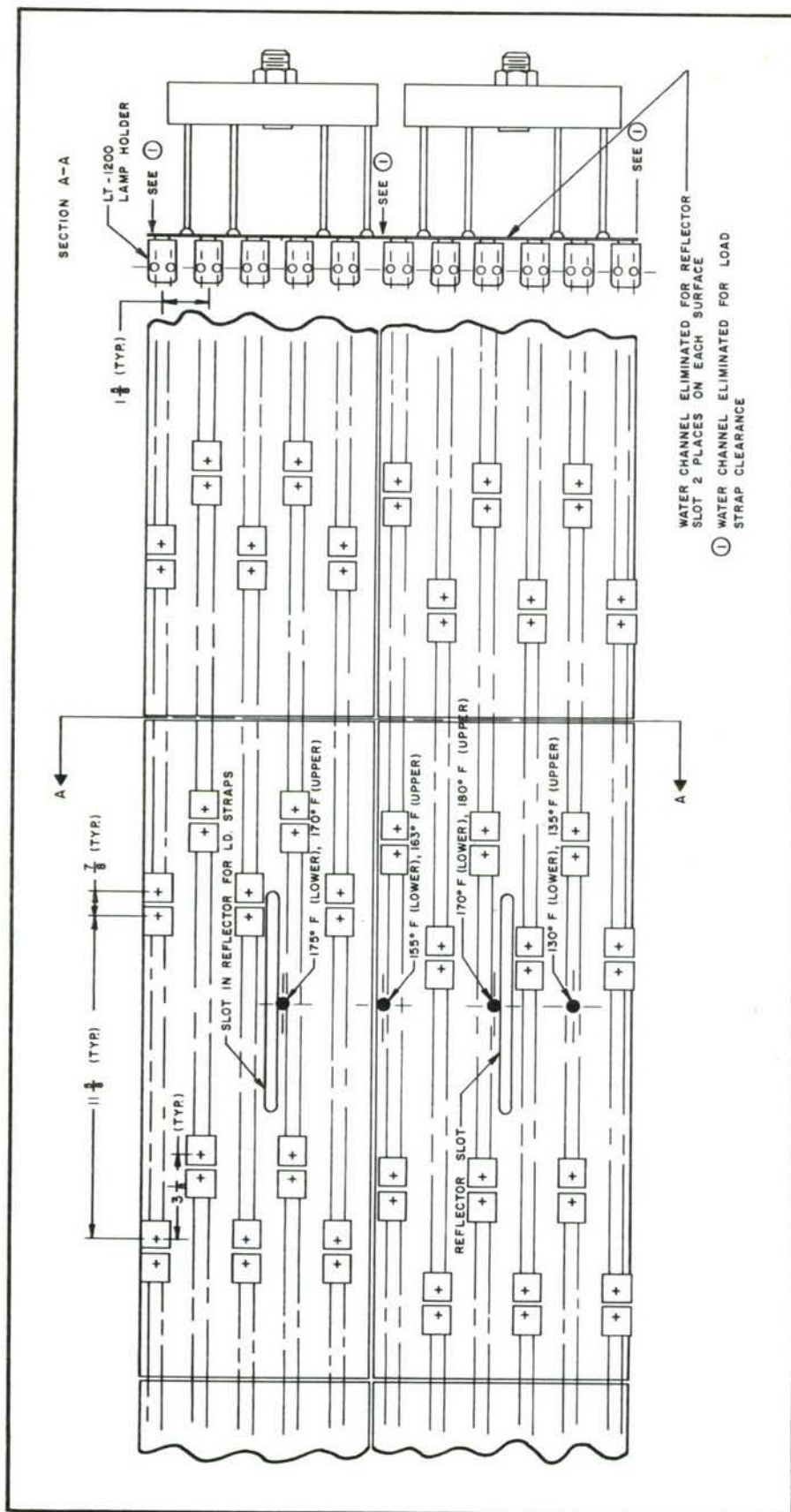


Figure 7. Temperature Distributions on Slotted Research, Inc., Water Cooled Reflector

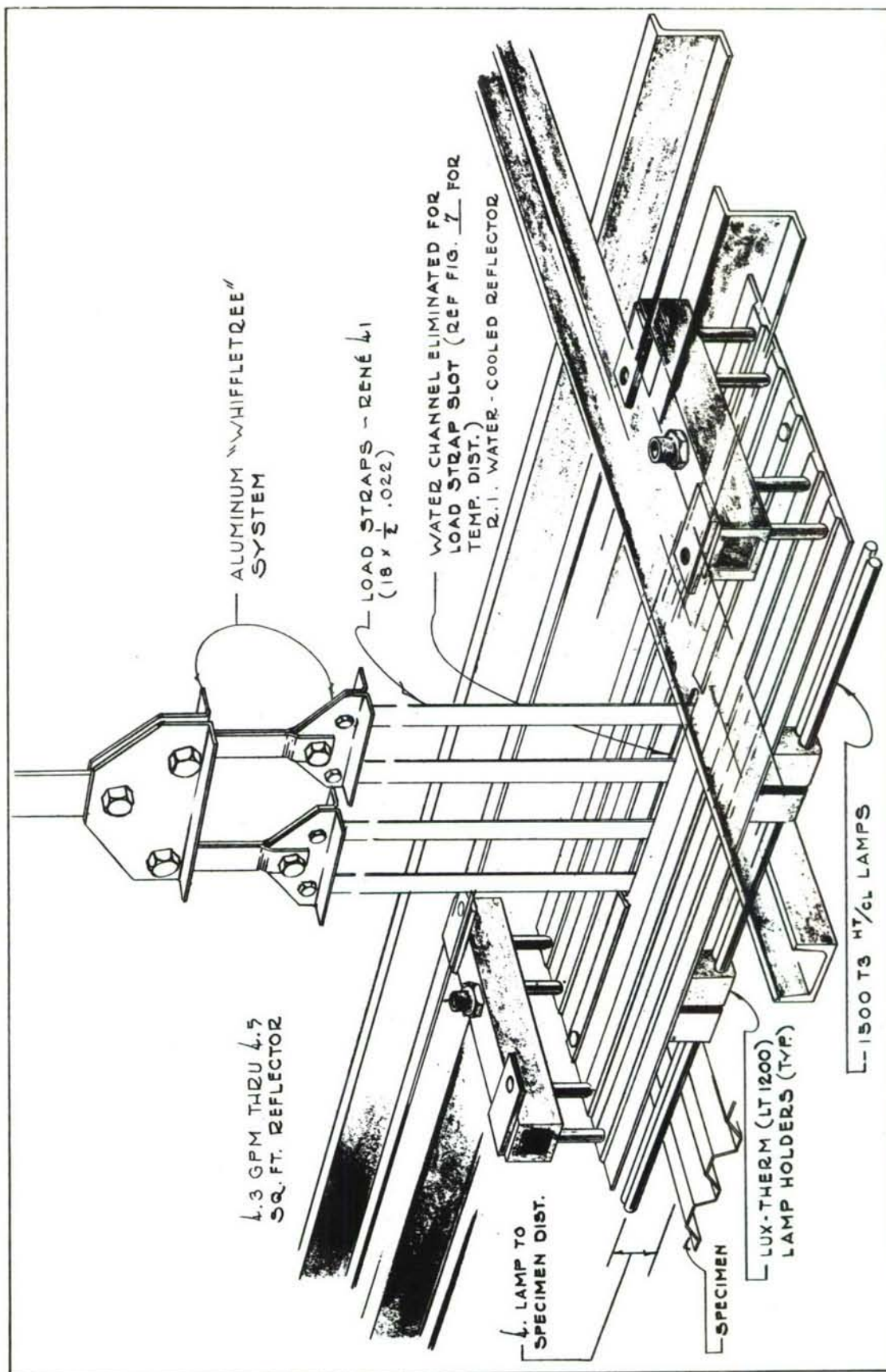


Figure 8. X-20 Eleven Slotted Water Cooled Reflector

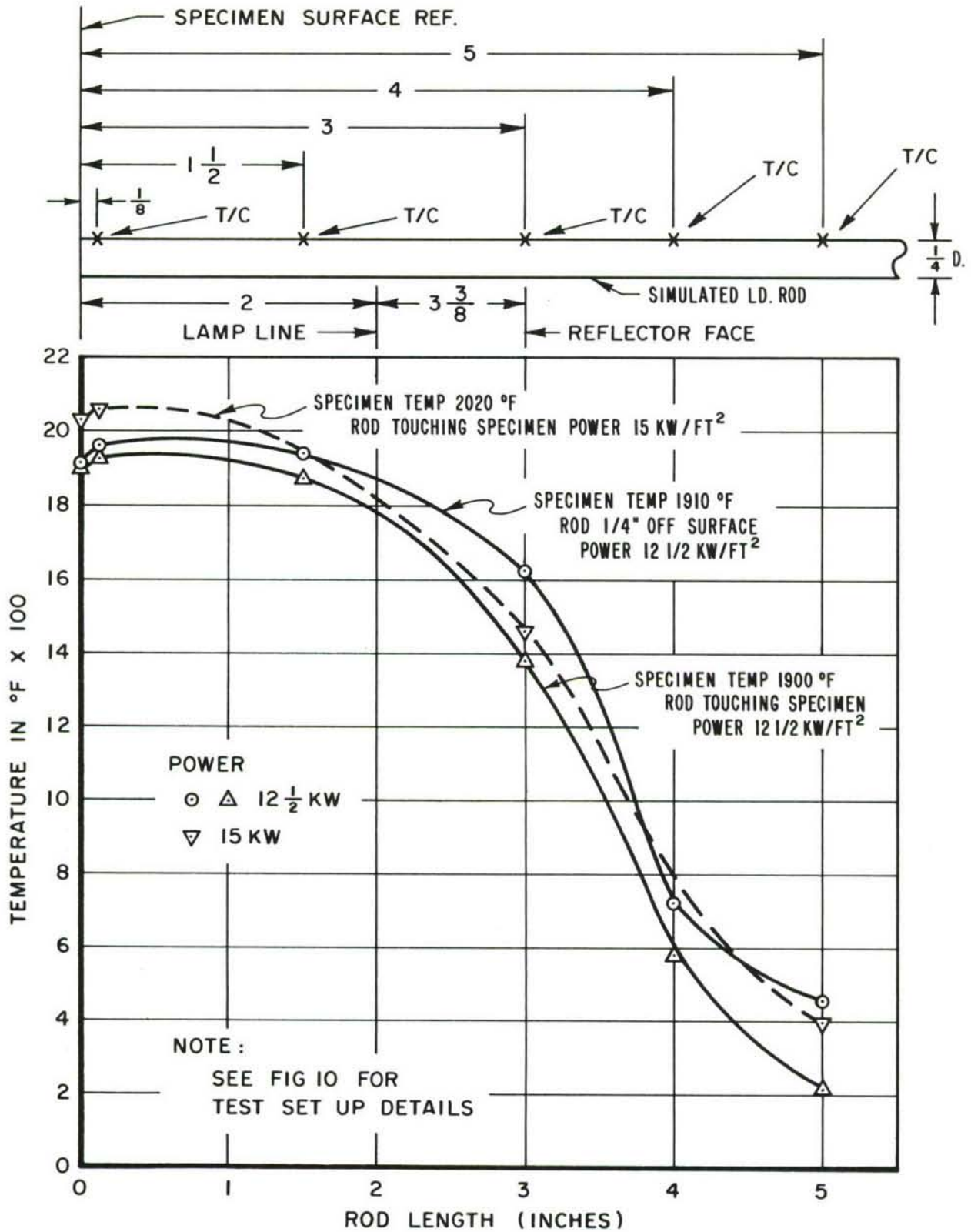


Figure 9. Temperature Distribution on Rod in Close Proximity to Heat Lamps

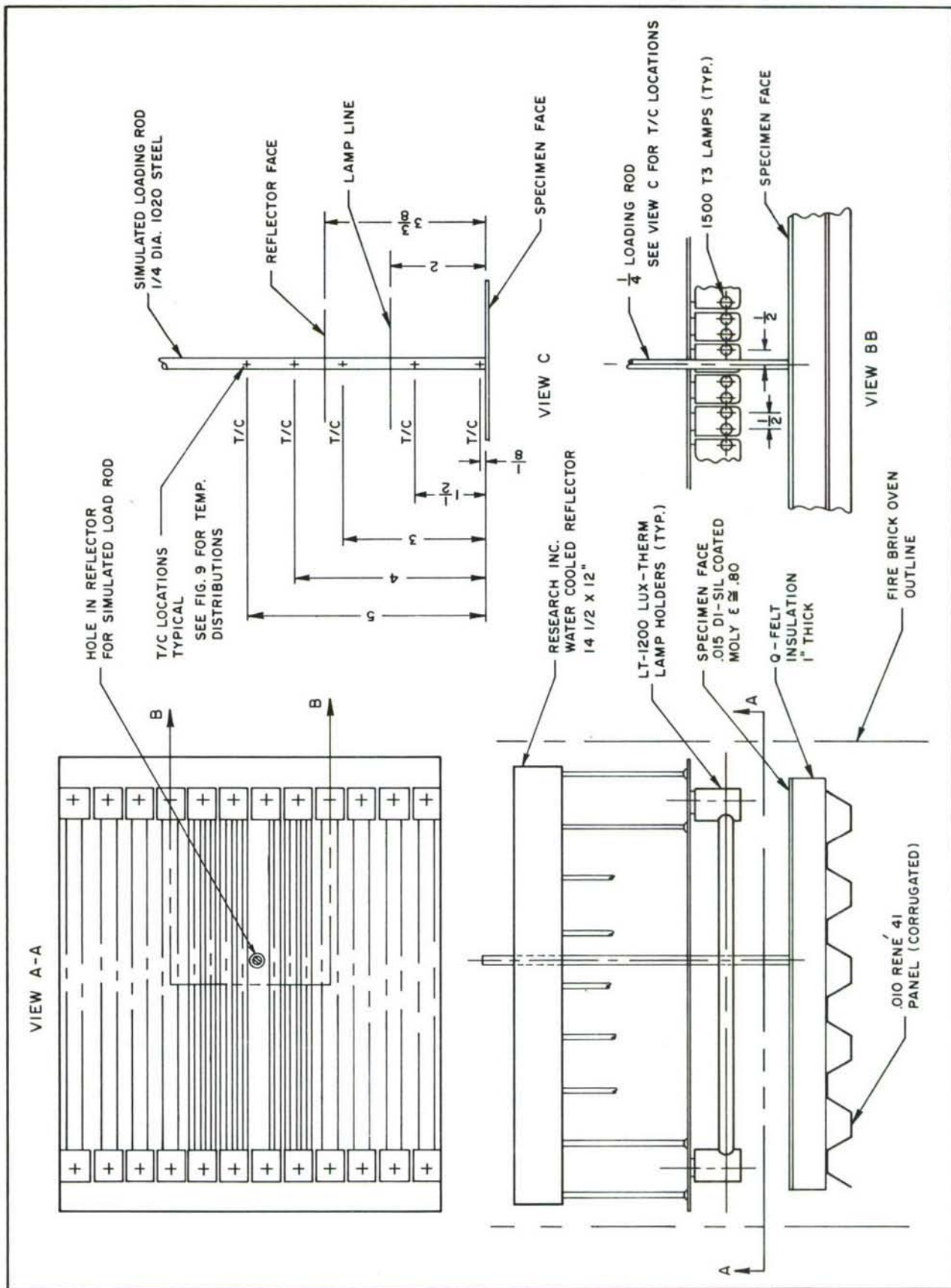


Figure 10. Test Set-Up for Load Rod Temperature Tests

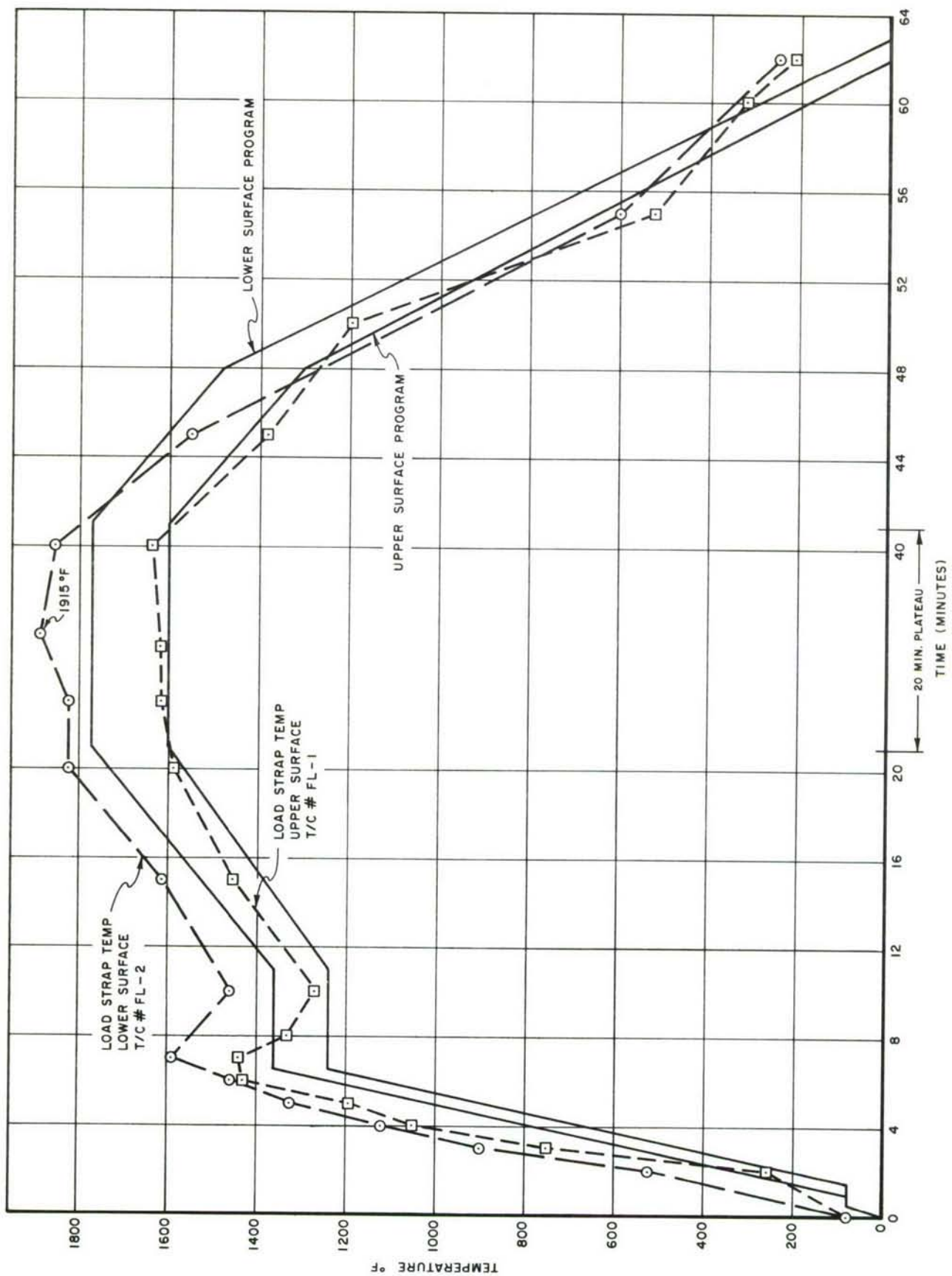


Figure 11. Temperature Distribution on Thin René 41 Load Strap in Close Proximity to Heat Lamps

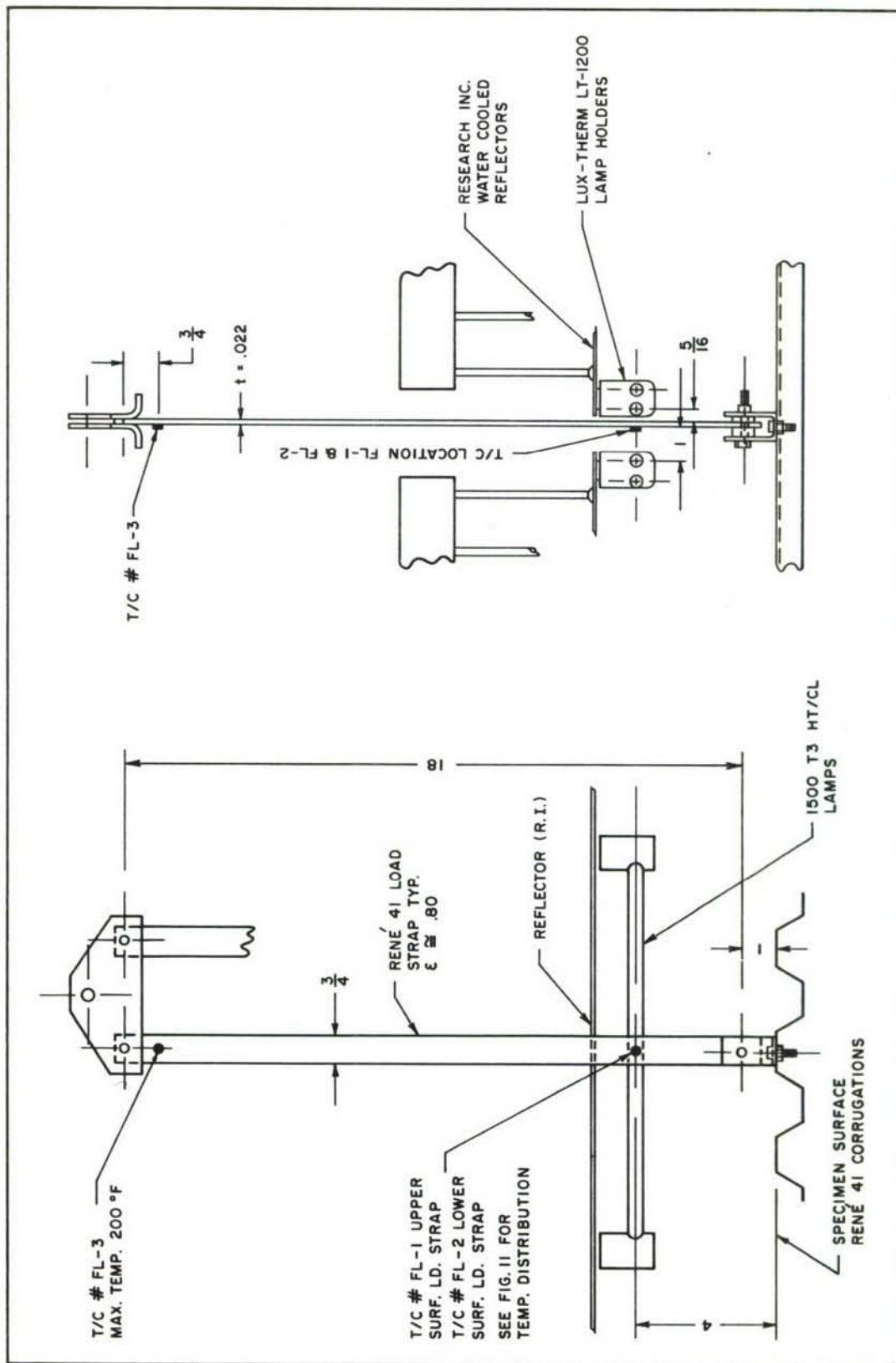


Figure 12. Load Strap and Heater Arrangement on X-20 Elevon

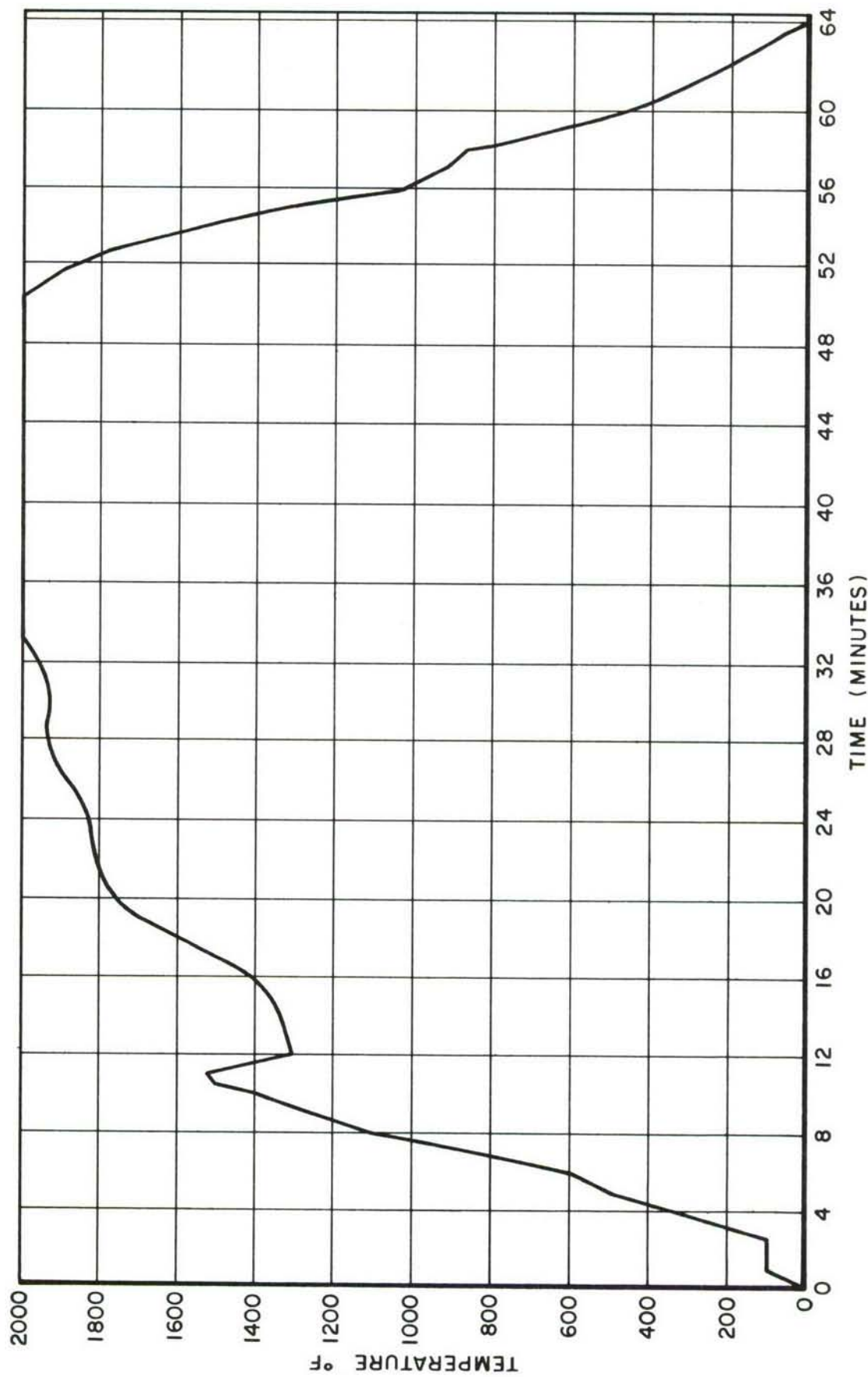


Figure 13. Time Temperature Program for Heater Evaluation

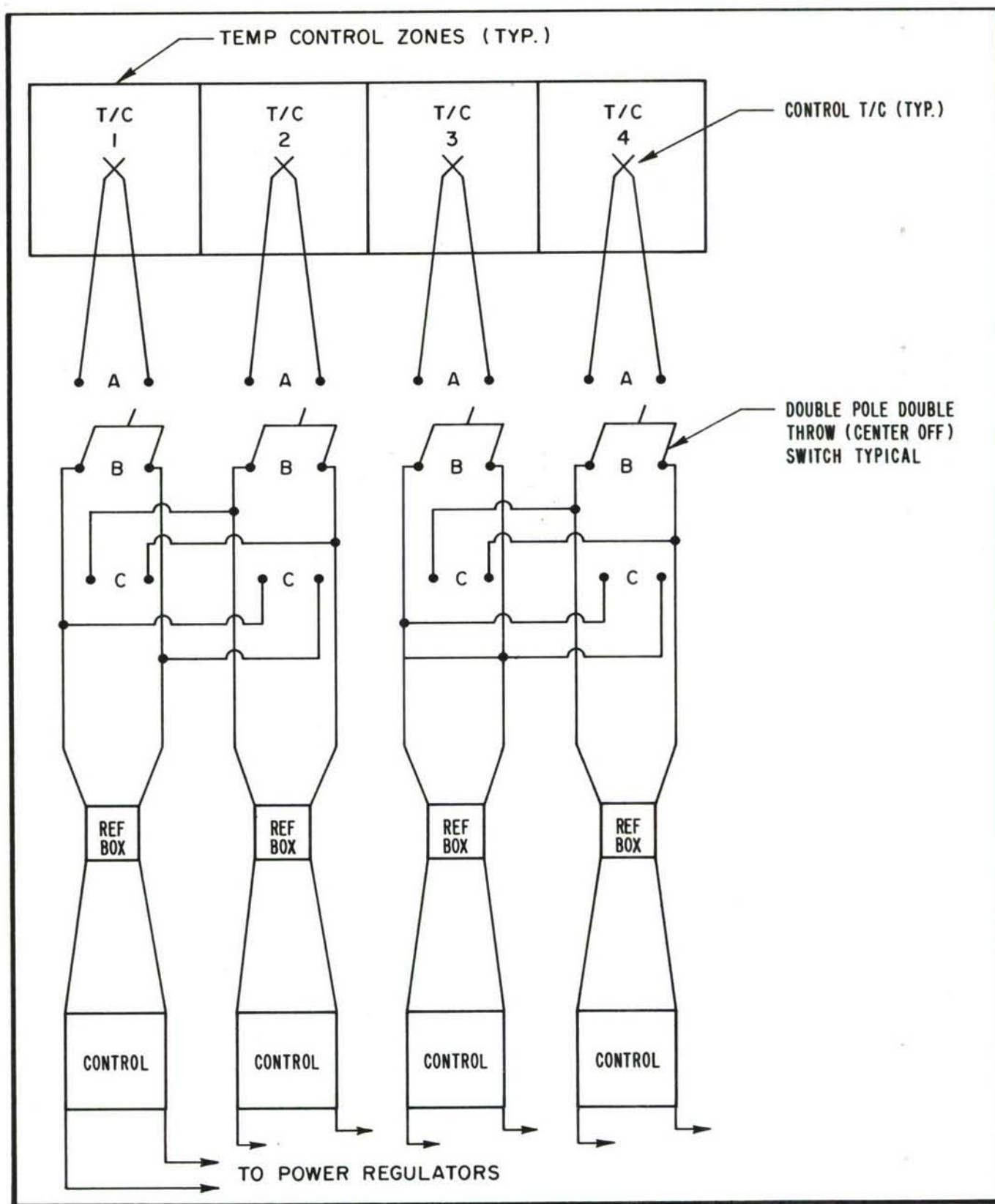


Figure 14. Thermocouple Switching System Used for the X-20 Elevon Test Program

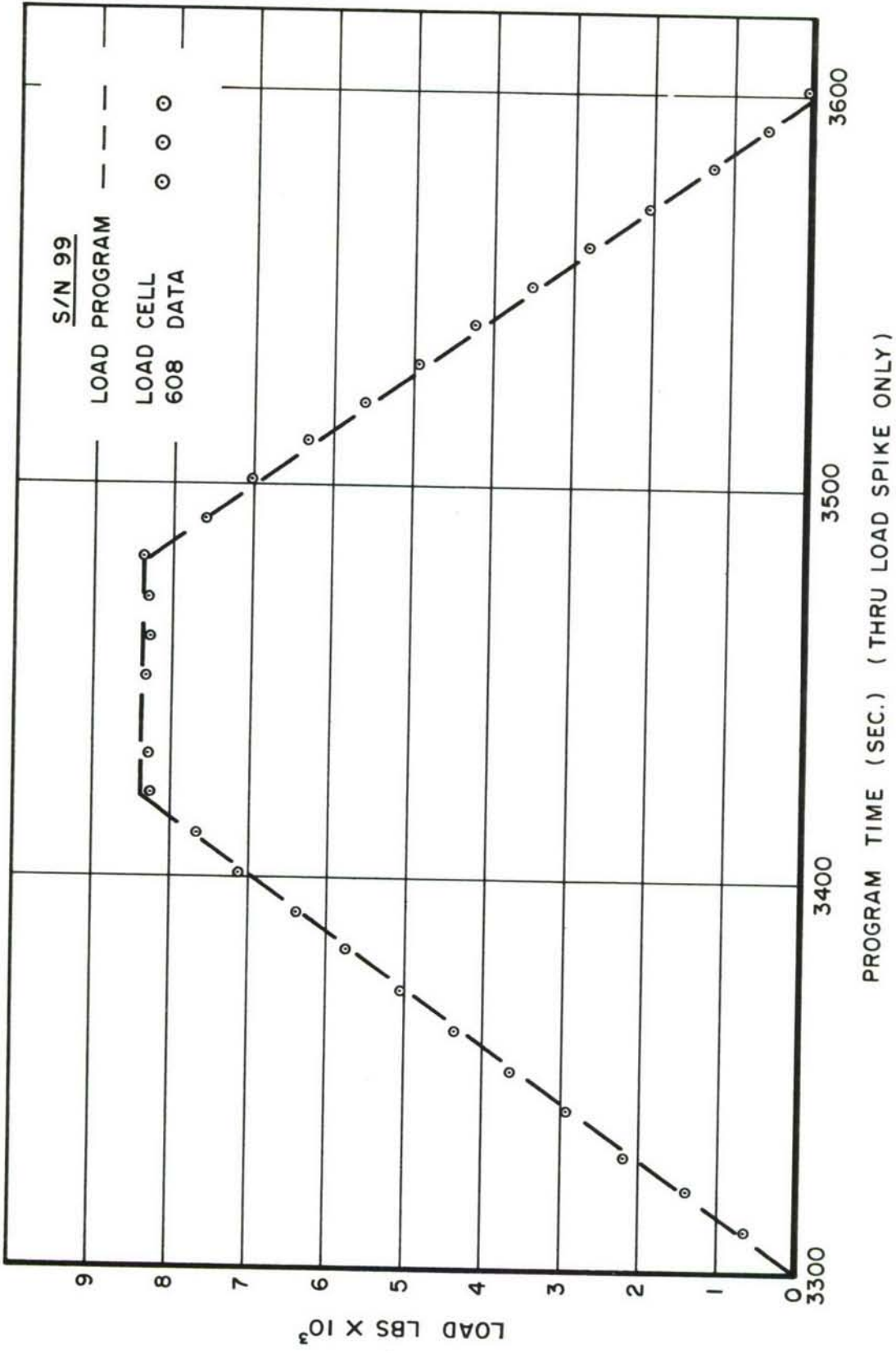


Figure 15. Comparison of Actual Load and Programmed Load from Edison Load System

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